Subjective listening test

In order to set the design goal for immunity it is necessary to establish the level of detected "GSM" noise which can be accepted by hearing aid users.

The "GSM" noise was recorded and later played-back at different levels to a panel of test persons. The noise was superimposed on different ambient noise back grounds: A quiet environment (pink noise at 35 dB SPL), a listening situation (speech at 65 dB SPL) and a slightly noisy environment (party noise at 55 dB SPL).

The result of the listening test showed that for a person with normal hearing the acceptable level of GSM noise is around 50 dB SPL in a slightly noisy environment. In a quiet environment the acceptance level is around 40 dB SPL which can be considered as the worst case situation.

Assuming that an acoustic response of 50 dB SPL is defined as being satisfactory for market entry it is possible to calculate the minimum acceptable distance from, e.g., a 2 Watt GSM terminal. The result of this calculation is given in Table 2. An 8 Watt GSM terminal shall be kept at twice this distance.

Table 2. Protection distance based on measured immunity

Hearing aid #	Minimum acceptable distance from a 2 Watt GSM terminal
20	-
21	0.5 meter
22	1.1 meter
23	1.2 meter
24	1.1 meter
25	1.1 meter
26	0.5 meter
27	0.5 meter
28	2.6 meter
29	1.6 meter
48	2.9 meter
49	0.8 meter
50	1.1 meter
51	2.4 meter

Test procedure

In order to ascertain if sufficient immunity has been achieved a test is performed where the Equipment Under Test (EUT), in this case the hearing aid, is exposed to a plane wave electromagnetic field.

The field strength, polarization and modulation should in principle simulate the effects of the environment and not the environment itself. This is an important difference. Testing is a diagnostic tool providing a measure of the performance allowing us to determine if the EUT can be expected to perform as intended in practice.

Modulation
The testing may be simplified considerably by using a sinusoidal amplitude modulation at , e.g., 1 kHz.

For hearing aids (as for most analogue audio equipment) the audio response to the electromagnetic disturbance is proportional to the modulation index and to the square of the RF carrier amplitude.

It can be shown that the audio response to a sinusoidal 80% amplitude modulation (which is a well established standard modulation form in RF immunity testing) within a fraction of a dB is identical to the audio response obtained with a "GSM"-like modulation provided that the RF test level is adjusted such that the peak amplitude of the modulated field is the same.

The advantages of the sinusoidal modulation are:

- that standard test equipment may be used;
- that the audio response may be measured selectively reducing the influence of ambient acoustical noise;
- when the modulation frequency coincides with the frequency already used for acoustical calibration then the audio response may be related to the input independently of the setting of gain controls.

Polarization
The standard procedure in immunity tests is to apply horizontally and vertically polarized fields. In the case of hearing aids only the polarization consistent with normal use is required, i.e.. vertically polarized fields. During the test the hearing aid shall be mounted with its vertical axis parallel to the E-field vector. It is particularly important that the interconnecting wire of body worn hearing aids are extended in the vertical direction.

Field strength
The field strength or test level shall be chosen according to the purpose of the test.

If the purpose is to ensure sufficient immunity to GSM telephones in the vicinity then a field strength of 10 V/m ensures a "protection distance" of approximately 1 meter from a 2 Watt terminal and approximately 2 meter from a 8 Watt terminal.

If the purpose is to ensure that the hearing aid user him- or herself can use a GSM telephone on the disabled ear, then the test level should be at least 50 V/m or perhaps even higher. In this case the hearing aid is in the near-field region of the GSM telephone which is different from the plane wave situation applied in the test. The level required to ascertain immunity GSM telephones at very close distance needs to be studied further.

Analogue telephones

The GSM-immunity of analogue, wire-connected telephones has been subject to a detailed investigation. As with the hearing aids, a large spread in the immunity of available instruments were found. The most susceptible telephones would detect the TDMA at a distance of 70 meter from an 8 Watt GSM terminal.

Conclusion

Basicly, immunity problems must be solved by fulfilling minimum immunity requirements. This is already anticipated in the EMC directive. Compliance to the existing draft standards for RF immunity will eliminate most of the immunity-problems.

Some special cases needs consideration: What level of immunity shall be required from a hearing aid, if the hearing aid user him- or herself shall be able to use a cellular radio with TDMA?

Restricted areas of limited size must be created in hospitals etc rather than the general prohibition now enforced.

Next generation of cellular could use CDMA, which would certainly ease the immunity problem for some electronic apparatus. Other way of achieving 'Spread-Spectrum' radiocommunication should however also be considered, CDMA is certainly not the only way to reduce the radiated power for the portable/mobile terminals in a cellular system.

Finally, it should be emphasized, that the GSM-induced disturbances, that Telelaboratoriet encountered in other electronic equipment (like fix-wired telephones and hearing aids) has primarily been due to insufficient immunity of the pertinent EMC-victim equipment. An electronic equipment fulfilling the electromagnetic field immunity requirements relating to the EMC-directive would in virtually all cases not be disturbed by a GSM-terminal.

TDMA-concepts in cellular system modulation schemes should therefore not be condemned at forehand as being unsuitable due to the EMC-experience gained from the introduction of GSM.

In the very near future, i.e. after january 1[st] 1996 only equipment, that fulfil the EMC-directive, may be brought to market. This was not the case, when GSM was introduced. This means, that all new electronic equipment must posses some minimum immunity towards external AM-modulated electromagnetic fields.

Therefore an effective protection distance can be calculated between a TDMA-based cellular terminal and a potential EMC-victim equipment. If some kind of 'Spread-Spectrum' concept were added to a TDMA-based system, most certainly such a system would operate fully EMC-secure in an environment with other electronic equipment having the required minimum immunity performance.

There is therefore no reason to discard the TDMA-option due to EMC-considerations. Furthermore the rather often claimed EMC-superiority of CMDA-system is basically due to the lower transmitter power achieved by the spectrum-spreading in the system. TDMA-systems like GSM and coming similar systems can also implement spectrum-spreading, and therefore enjoy lower transmitter powerlevels.

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3

DIGITAL CELLPHONES &

INTERFERENCE WITH

HEARING AID USERS

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ACNOWLEDGMENTS

The cooperation and assistance of Simon Cooke-Willis (Telecom Cellular), Brian Erikson and James Norman (BellSouth) is acknowledged.

Jeremy Rosser, Senior Audiologist, National Audiology Centre, assisted with data collection for this project.

This project was carried out on behalf of the Ministry of Health, through a contract administered by North Health.

The cooperation of the Auckland Branch of the Hearing Association in making its rooms available is gratefully acknowledged. Polly Sussex, Principal Tutor of the Hearing Association helped to recruit subjects, as did Dilworth Audiology.

INTRODUCTION

Digital cellphone systems recently introduced in New Zealand use a technology known generically as time division multiple access (TDMA). Signals are sent out as a series of short pulses. The time between pulses, and hence the frequency, varies between the two major systems:

DAMPS (Digital Advanced Mobile Phone Service) - an American system - has a pulse frequency of around 50 Hz.

GSM (Global System for Mobile communication) - a European developed system - in which the pulse frequency is 217 Hz.

The pulse envelope generated by turning the carrier on and off represents a 100% AM modulation of the carrier. The pulse frequencies are within the range amplified by hearing aids and the interference they produce is perceived as a buzzing sound. Studies of the phenomenon show that the radio signal is detected at the input stage of the hearing aid, and thence amplified, by up to 30,000 times (Otwidan, 1991).

The interference problem with hearing aids is thus due to the essential nature of the emissions, and is not an incidental by-product which might for example, be solved by improved shielding of the cellphones.

A number of studies (all unpublished) have been carried out around the world into the effects of digital phones on hearing aids (along with other electronic devices such as cardiac pace-makers and electronic wheelchairs).

The Otwidan report (1991), compiled by a consortium of Danish hearing aid manufacturers, simulated a GSM field and measured its effect on the performance of 14 different hearing aids. The highest acoustic output and the frequency at which this occurred (invariably a harmonic of 217 Hz) was recorded and the equivalent input sound intensity was calculated. The simulated signal produced high level signals equivalent to more than 60 dB input, in one body-worn and one BTE hearing aid. In other BTE and ITE aids, interference was equivalent to intensities of between 21 and 35 dB, and 6-25 dB respectively.

Orientation of the phone has been found to affect interference. The effect depends on the placement of the printed circuit boards within the hearing aid (Otwidan, 1991). With the ever-decreasing size of hearing aids, this is likely to be more variable as manufacturers struggle to fit electronic components into smaller volumes.

Metallising hearing aid cases was found to reduce susceptibility from 4 to 12 V/m (10 dB) in the British Department of Trade & Industry's Radiocommunication Agency's report. However, such modification would mean that hearing aid telecoils could not be used, and this would prove a major limitation for many hearing aid wearers.

The National Acoustic Laboratories in Australia (Joyner et al, 1993) measured interference defined as an increase in output of 10 dB above the noise floor in a range of hearing aids, and concluded that GSM phones posed a considerable hazard to hearing aid users.

With the recent introduction of the two types of digital phone systems in New Zealand, the Hearing Association and the National Foundation for the Deaf, concerned at the implications for hearing aid users, asked for further informati was decided that the prime need was for a study examining the impact of interference on hearing impaired hearing aid users.

In New Zealand, mobile cellphones in current use have a maximum power output of 2 Watts. The higher powered 3 and 8 Watt models are available only as transportable or car-mounted units. However, there is no regulation to prohibit introduction of higher powered mobile phones, and consequently 8 Watt phones were included in this study.

METHOD

Subjects

Subjects were 29 hearing impaired adults, all regular hearing aid wearers. The mean age was 49.7 years (range 24-83 years). Fifteen were male, and fourteen were female.

Of those subjects who were binaurally fitted with hearing aids, the test ear was chosen as the subject's preferred ear. In twelve cases, the hearing aid on the right was tested, and in 17 cases, that on the left. The mean hearing loss for the relevant ear was 64 dB HL (PTA range 29-108 dB).

The distribution of degree of hearing loss and types of hearing aids tested is presented in Table 1.

Table 1. Number of subjects with various degrees of hearing loss, and using various types of hearing aids. Mild: PTA <56 dB HL; moderate: 56-85 dB HL; severe: >85 dB HL; BTE: Behind the Ear, BTE/mic: BTE with external mic; ITE: In the Ear; ITC: In the Canal.

	Mild	Moderate	Severe	Total
BTE/mic	0	0	1	1
BTE	0	6	4	10
mini BTE	2	3	0	5
ITE	5	2	0	7
ITC	3	3	0	6
Total	10	14	5	29

Hearing aids tested were of six different brands and were distributed in the following way:

Table 2. Numbers of each brand of hearing aid tested.

Brand	Bernafon	Danavox	Oticon	Phonak	Starkey	Widex
No.	2	3	8	9	3	4

Equipment

Cellphones tested were a variable power GSM phone (model Orbitel TMT 900), which was tested on three power settings - 8 W, 2 W and 0.8 W, and a dual AMPS phone (AMPS/DAMPS Ericsson TR207) with digital and analogue settings both of 0.6 W. Cellphones were operated independently in service mode so that power levels could be set and fixed, to override the normal network control of the phone's power level. Modulation and frame rates were identical to normal system operation.

Field strength was measured using a spectrum analyzer connected to a dipole antenna, in dBm, and this was later converted to V/m.

Procedure

Subjects were seated sideways in a long room (16m by 4.5m) in a wooden building in a quiet suburban setting, with no major metal reflectors within 10m radius. The room was fitted with a loop system which was operational during testing of the hearing aids' telecoils.

The subject's test ear faced the length of the room. Those subjects who were binaurally fitted with hearing aids were asked to remove the hearing aid from the non test ear. The subjects' hearing aids were set to user volume.

Subjects were questioned concerning any electrical interference with their hearing aids they might have previously experienced.

Phone presentation order varied in a predetermined sequence. Subjects were asked to close their eyes and to describe any sound they heard through their hearing aid when a phone was brought close.

The phone was moved further away until they could no longer detect the sound. The phone was then brought closer until they were just able to hear the sound again, still with their eyes closed. They were asked to hold a hand up while they heard the sound and put it down when the sound disappeared. This procedure was repeated twice in order to confirm that the subject's thresholds were reliable.

To minimise errors due to signal reflections, measurements were conducted by "spatially stirring" the phone antenna while walking towards and away from the subject. The distance corresponding to the threshold of detectability was recorded. The field strength was also recorded. The dipole antenna was "stirred" near the subject's hearing aid to reduce measurement errors. If the distance between the subject and the phone was less than 0.5m, the field strength was not recorded because of overload and relative position errors.

The procedure was repeated for the different settings and types of phones. If the hearing aid had a telecoil (true in 16/29 cases), readings were also obtained in this condition for each type and power of phone.

Next, subjects were asked to listen to running speech produced live voice by a male speaker at an average conversational level of 65 dB(A), and to indicate on the rating scale provided, (see Appendix 1) which condition applied to them as the phone was interference became annoying, making speech difficult to hear (rating three on the scale). This procedure was repeated twice to check the consistency of the subject's report. The distance and field strength at which a rating of three was given were recorded. This procedure was performed using the subject's hearing aid microphone only (not the telecoil).

RESULTS

Twenty four of the 29 subjects described the GSM interference as a buzzing or humming sound. Subjects' descriptions of the DAMPS interference were more varied; examples include: throbbing, static, purring or a lower pitched buzz compared to the GSM sound.

No subjects reported any interference from the Analogue phone.

Nineteen subjects reported no previous experience of interference detected through their hearing aid(s). The remaining ten subjects had experienced interference from a range of sources including fluorescent lights, car indicators, computer cables, shop door openers and shop security detection units.

The interference detection threshold varied considerably. Typically it was less than one meter. In a few cases, there was no interference, and in two cases, interference from the 8W phone was reported at a distance exceeding 5 meters. In a few cases interference through the hearing aid was clearly audible to the normal hearing experimenters, well before it was responded to by the hearing aid wearers. Detectability data for the various powered digital phones are presented in Table 3.

Table 3. Number of people detecting interference at various distances, shown by power of digital phones (hearing aid microphone data only)

	Detection threshold (m)					
Phone	No interference	<1	1-2	2-5	>5	Total
8W	0	16	7	4	2	29
2W	2	21	2	4	0	29
.8W	7	18	2	2	0	29
[illegible]	5	24	0	0	0	29

In 19.8% of trials, interference occurred at a distance exceeding 1 meter. If the 8W cellphone was ignored, this reduced to 11.5%.

The equivalent data for speech disruption is presented in Table 4. In 3.9% of trials, speech disruption occurred at a distance exceeding 1 meter. If the 8W cellphone was ignored, this reduced to 2.3%.

Table 4. Number of people showing speech interference at various distances, shown by power of digital phones (hearing aid microphone data only).

Phone	Speech Disruption (m) No Speech Disruption	<1m	1-2m	2-5m	>5m	Total
8W	4	10	1	1	0	16
2W	13	15	0	1	0	29
.8W	13	15	0	1	0	29
.6W	18	11	0	0	0	29

Field strength measurements were frequently unmeasurable. Results are presented in Tables 5 and 6.

Table 5. Number of people detecting interference at various Volts/m, shown by power of digital phones (hearing aid microphone data only)

Phone	Detection threshold (V/m) Unmeasurable	>10	7-10	3-7	<3	Total
8W	11	0	1	13	4	29
2W	15	0	1	10	3	29
.8W	19	1	1	6	2	29
.6W	20	0	0	6	3	29

Table 6. Number of people with speech discrimination interference at various Volts/m, shown by power of digital phones (hearing aid microphone data only).

Phone	Speech Disruption threshold (V/m) Unmeasurable	>10	7-10	3-7	<3	Total
8W	12	0	1	2	1	16
2W	21	0	1	6	1	29
.8W	23	0	0	5	1	29
.6W	25	0	0	4	0	29

The impact on detection of interference of the type of hearing aid is shown in Table 7. Equivalent results for speech disruption are given in Table 8.

Table 7. Mean distances at which interference was detected shown by type of hearing aid and by power of digital phones. Both microphone & telecoil data are included.

Phone	Detection (m) BTE/mic	BTE	miniBTE	ITE	ITC	Total
8W	7.3	1.2	1.2	1.6	0.5	2.4
2W	5.3	0.6	0.8	0.9	0.3	1.6
.8W	2.8	0.3	0.4	0.7	0.2	0.9
.6W	0.5	0.1	0.2	0.2	0.0	0.2
Total	4.0	0.6	0.7	0.8	0.3	1.3

Table 8. Mean distances at which interference affected speech discrimination, shown by type of hearing aid and by power of digital phones.

Phone	Speech Disruption (m) BTE/mic	BTE	miniBTE	ITE	ITC	Total
8W	4.2	0.9	0.6	0.0	0.2	1.2
2W	2.5	0.4	0.4	0.0	0.1	0.7
.8W	2.3	0.3	0.2	0.0	0.0	0.6
.6W	0.3	0.2	0.0	0.0	0.0	0.0
Total	2.3	0.5	0.3	0.0	0.0	0.6

Table 7 shows less of a problem with ITCs than ITEs or BTEs. This difference was statistically significant (see Table 9). However, there was no difference between susceptibility of ITEs and BTEs. A possible explanation is that although the interference may have been present in these larger aids, the wearers have significant hearing losses, (6 moderate and 4 severe) and they may not have responded to low level interference.

Table 9. Results of analysis of variance.

	F	df	p
Detection distance			
Phone Power	3.1	3	<.05
Hearing aid type:			
(ITC vs ITE, BTEs)	5.1	1	<.05
Power*type	0.8	3	n.s.
Error		100	

Table 10 gives equivalent data for all hearing aid types, and for both distance measures. In this comparison, the power of the phone, the type of hearing aid and their interaction were highly significant.

Table 10. Results of analysis of variance.

	F	df	p
Detection distance			
Phone Power	26.9	3	<.001
Hearing aid types (all)	28.0	4	<.001
Power*type	3.9	12	<.001
Error		155	
Speech interference distance			
Phone Power	10.9	3	<.001
Hearing aid type	6.3	4	<.001
Power*type	2.7	12	<.005
Error		89	

The degree of hearing loss also had a significant effect. The threshold at 250 Hz proved a stronger covariate ($F=17.4$, $p=0.0001$) than did the pure tone average ($F=12.3$, $p<0.001$).

Analysis of variance based on the distance at which interference was detected showed that there were no significant differences using hearing aid microphones or telecoils.

Nor was there a significant difference between the GSM and DAMPS types of phone - apart from the over-riding impact of the different powers available.

There was no significant effect of brand of hearing aid, nor did the age of the hearing aid contribute significantly to the variance.

The people most affected by interference were the single subject with a BTE hearing aid with a separate microphone on a long lead, one with an older model of ITE, and a third with a new BTE, of new technology, which was not associated with significant problems with the two other subjects who were fitted with the same model.

Three subjects wore digitally programmable BTEs with remote controls. Two of these subjects had remote controls which were inductively coupled to the hearing aids. Neither of these remotes failed to work in the worst possible test condition, ie. using an 8W phone at the ear. The other subject, whose remote control operated using an RF signal, reported that the remote ceased to operate under these test conditions but continued to work with phone systems of 2W and below.

DISCUSSION

Studies done overseas which have failed to consider the wearer of the hearing aid have suggested that the chances of detecting interference is greater the larger the hearing aid is. The present study has shown that this relationship does not necessarily hold as the hearing abilities of the hearing aid user also need to be considered.

Canal hearing aids emerged as significantly less prone to interference than ITE or BTE models. There was no difference in susceptibility between ITE and BTE models.

One of the most dramatic effects found in the present study was with one subject with a severe hearing loss, who used a BTE with an external microphone. A similar effect could be predicted with the use of a hearing aid connected to an audio input system. This effect was predicted by the Otwidan report (1991).

In this study, three individuals with the same model of hearing aid were tested. One experienced interference readily, although the other two did not. Hearing aid design is clearly not the only critical variable.

The present study showed little difference between the susceptibility of microphone and telecoil, similar to the findings of the Otwidan report (1991).

Speech interference measures are probably the most valid measure of problems in "real life" since the mere detection of a sound in the absence of any other external stimuli does not bear much resemblance to a real life situation

The next step in evaluating the impact of interference from digital cellphones is to model the amount and type of interference likely to be experienced by hearing aid wearers in real life. In Jon Short's modelling study of the impact of phone interference on hearing aid wearers, he estimated that a hearing aid wearer walking on central London streets would experience 3 seconds of interference every 8 minutes. However, this study assumed that a hearing aid user would always detect interference when it occurred. Such is clearly not the case.

Results from this study indicate that the immunity level of 3 V/m proposed under the European Community's electromagnetic compatibility directive is inadequate. From Tables 5 and 6 it can be seen that a significant proportion of subjects experienced interference at power levels between 3 and 7 V/m, and a more appropriate criterion would be 7 V/m, if not 10 V/m as suggested in the 1993 report of the Working Group convened by the Danish Ministry for Communications and Tourism.

The European Telecommunications Standards Institute recommends a combination of strategies to eliminate the problems produced by digital telephones. Some reduction might come by improving hearing aid design and immunity, but it might still be necessary to place constraints on the introduction of the telephone technology to:

a) keep transmission power minimal
b) restrict urban cell sizes
c) implement discontinuous transmission (DTX) where possible
d) choose base site locations carefully in order to minimise interference with electrical equipment.

Recommendations flowing from the present study are:

a) The introduction of digital cellphones should be monitored to prevent the introduction of high powered devices, and to ensure that the volume of transmissions does not pose a threat to the quality of life of hearing impaired people.

b) Consumers should be informed about the possible effects on hearing aid users associated with digital cellphone operation.

c) Hearing aid wearers should be informed that they will be unable to use digital cellphones.

d) Hearing aid wearers should be informed that they may experience interference from digital cellphones, and of appropriate ways to reduce the interference (eg identifying the source of the interference and either moving away from it, or asking the cellphone user to move away from the hearing aid user).

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APPENDIX 1

1. No interference detected

2. Interference can just be heard - speech is still easy to hear

3. Interference is annoying - speech is starting to become difficult to hear

4. Interference is making speech very difficult to hear

5. Interference is uncomfortably loud

4